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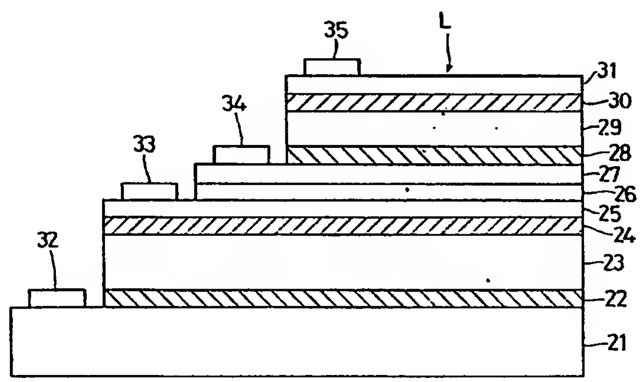
GB A 2083705
GB A 2047463
GB A 2030359

(58) Field of search
H1K

(54) Colour sensitive photodetector

(57) The sensor comprises a substrate 21, a first amorphous photovoltaic element having a PIN structure 22-24 formed on the substrate, a transparent insulated layer 26 formed on the first element, and a second similar element 28-30 formed on the transparent insulation layer. The two elements have different frequency responses.

FIG. 1



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SPECIFICATION

Color sensor

Background of The Invention

Field of the Invention

This invention relates to a color sensor, and more particularly to a color sensor composed by utilizing the photoelectric effect of an amorphous solar cell which is a photovoltaic element.

Description of the Prior Art

When light is irradiated to a semiconductor substrate having a PN junction, excessive carriages are generated by luminous energy hv. The electrons and holes generated drift to the N-type region and P-type region, respectively, and while the PN junction is opened, voltage is detected by the amount equivalent to the variation of the Fermi level, and when it is short-circuited, short-circuit current flows in the direction of P-type to N-type. A semiconductor device which utilizes such a photoelectric transducing mechanism has been widely used as a photo transistor, a photo diode, a solar cell or the like.

When light is irradiated to a semiconductor substrate as described above, the absorption coefficient of light largely depends on wavelength, though the degree of dependence varies according to the materials of the substrate such as Si or Ge. Light of a short wavelength, which has large luminous energy, is absorbed in the vicinity of the surface of the semlconductor substrate, thereby generating electron-hole pairs, while light of a long wavelength reaches a comparatively deep portion and is absorbed there.

On the basis of this principle, a semiconductor color sensor which is composed of a single-crystal Si chip having receptor elements formed in a double structure therein, and utilizes the thickness of Si as a filter or uses a specific filter has been proposed and put into practice (Japanese Patent Laid-Open No. 16494/1980).

Fig. 5 is a schematic view of the structure of a conventional color sensor which uses a single-crystal silicon and Fig. 6 is an equivalent circuit diagram of the sensor shown in Fig. 5. In these figures, the referential numeral 1 denotes a P layer, 2 an n layer, 3 a P layer, and 4, 5 and 6, respectively, electrodes.

As it Is clear from the figures, the color sensor shown in Fig. 5 is a semiconductor color sensor of a type which uses as a filter the thickness of Si of a single-crystal silicon chip having a receptor element formed in a double structure therein, and utilizes the difference in spectral sensitivity characteristics between a shallow junction type photo diode D1 and a deep junction type photo diode D2. As is described above, the shallow junction type photo diode D1 has large sensitivity to light of a short wav l ngth, while the deep juncti n type photo diod has larg sensitivity to light of a long wavel ngth. By utilizing the fact that th ratio of short-circuit currents of th two photo diod s D1 and D2 corresp nds to wavel ngth by 1 t 1, th color sensor shown in Fig. 5 can discriminat the col r of the light which has ent red from the upper surface of the color sensor.

In the single-crystal color sensor shown in Fig. 5, however, it is necessary to make the thickness of the silicon semiconductor layer ordinarily more than 10μm in order to obtain a desired sensitivity to wavelength (300 to 800 nm), and furthermore, a temperature not lower than 1,000°C is required for treatment of doping of impurities and thus the manufacturing process is complicated.

On the other hand, a color sensor has been proposed which uses an amorphous single-crystal silicon and color filters in combination therewith which can be formed at a comparatively low temperature (300 to 400°C) and has a thin layer as compared with a single-crystal silicon. Fig. 7 is a schematic view of an example of the structure of a conventional color sensor using amorphous silicon and Fig. 8 is an equivalent circuit diagram of the sensor. In these figures, the referential numeral 11 represents amorphous silicon, 12 a transparent conductive film, 13 a glass substrate, 14 to 16 color filters corresponding to R, G, and B, respectively, and 17 to 20, respectively, electrodes. filter

This color sensor can discriminate the color of the light which has entered from the filter side on the basis of the output of each photo diode corresponding to each color filter.

Such a color sensor as shown in Fig. 7 using amorphous silicon, however, is defective in that though it is possible to make the thickness of silicon smaller, it is necessary to use three kinds of color filters, and the output of a filter is apt to vary depending upon the incident angle of light in relation to the color filter and is sensitive to the influence of stray light.

Accordingly, it is an object of the invention to eliminate the above-described defects and to provide a color sensor which has a thinner silicon layer, dispenses with the need for a specific color filter and can be produced by a simple manufacturing process.

This invention is based on the unexpected finding that the device obtained by forming a receptor element in a double structure in an amorphous silicon semiconductor layer having a PIN structure exhibits wavelength dependency characteristics approximately equal to those of such a conventional single-crystal silicon device composed of a double receptor element as is shown in Fig. 5, in spite of having being very much thicnner than the conventional one. This phenomenon may be interpreted to be based on the fact that the light absorption coefficient of amorphous silicon is remarkably large compared with that of single-crystal silicon. amorphous silicon

Summary of the invention

T achi ve th above-described aim, this inv ntion provides a color sens r comprising:

a substrate;

a first am rphous photovoltaic element having a PIN structure which is f rmed on the substrate;

a transparent insulated layer formed n the first amorphous ph t voltaic l ment; and

a sec nd am rphous ph tovoltaic element having a PIN structure which is formed on the transparent insulation layer.

In a color sensor according to the invention, which is composed of amorphous photovoltaic elements, the thickness of a semiconductor layer can be formed very much thinner than that of a conventional semiconductor color sensor. Furthermore, since it is unnecessary to use a specific color filter and it is possible to compose the color sensor by low-temperature treatment, the manufacturing process is simplified as compared with a conventional one, resulting in an easy and low-cost production. Such a color sensor is effective for color discrimination of colored paper, reading of color codes, color examination of pigments and dyes, color discrimination of thread and yarn, adjustment of color balance in television, color adjustment of color copy, color detection of other objects, measurement and control of color temperature and wavelength of light source, and the like.

Brief description of the drawings

Figure 1 is a schematic view of the structure of an embodiment of a color sensor according to the invention;

Figure 2 is an equivalent circuit diagram of the embodiment shown in Figure 1;

Figure 3 shows the spectral sensitivity characteristics of a color sensor according to the invention;

Figure 4 shows the dependency of the ratio of short-circuit current on wavelength;

Figure 5 is a schematic view of the structure of a conventional color sensor;

Figure 6 is an equivalent circuit diagram of the color sensor shown in Figure 5;

Figure 7 is a schematic view of the structure of another conventional color sensor;

Figure 8 is an equivalent circuit diagram of the color sensor shown in Figure 7; and

Figure 9 is a graph showing the relationship between the thickness and the maximum absorption wavelength of an amorphous photovoltaic element used for this invention.

Description of the preferred embodiment

As a substrate of a sensor according to the invention, a glass plate or a stainless steel plate is suitable.

An amorphous photovoltaic element of a PIN structure in this embodiment denotes an element composed of a P-type amorphous semiconductor layer and an N-type amorphous semiconductor layer with what is called an I-type amorphous semiconductor layer inserted therebetween. The I-type amorphous semiconductor layer is preferably as thick as possible in comparison with the P-type and N-type layers.

transparent insulated SiO_2 layer

A first am rphous ph tovoltaic element is overlaid with a second amorphous ph t voltaic element thr ugh a transpar nt insulated layer f SiO_2 or th like which is f rmed by depositi n or the lik . Th thickn ss of th insulated layer is preferably about 0.005 to 0.1 μm.

Each f th amorphous photovoltaic lements can be produced under ordinary conditions. That is, it can be produced by a repetition of the steps of: introducing material gas for manufacturing a semiconductor under a vacuum (0.1 to 3 Torr); subjecting the material gas to plasma decomposition by plasma generated by a discharge power of 0.02 to 2 W cm^{-2}; and depositing the semiconductor film on a substrate which is heated to 150 to 300°C.

Gas having lower alkylsilane such as monosilane and disilane as the main ingredient, diborane as an impurity source, and containing hydrogen and argon, will be cited as an example of material gas for manufacturing a P-type semiconductor layer. As an example of material gas for manufacturing an N-type semiconductor layer, gas having lower alkylsilane as the main ingredient and phosphine as an impurity source and containing hydrogen will be cited. Gas having lower alkylsilane as the main ingredient and containing hydrogen is to be mentioned as an example of material gas for manufacturing an I-type semiconductor layer.

A compound semiconductor such as Ga-As semiconductor and In-P semiconductor may also be used.

The thickness of the entire semiconductor layer composed of the first and second amorphous photovoltaic elements is variable according to the wavelength range of light utilized for detection, especially according to the limit relative to a long wavelength, but with respect to ordinary light of a wavelength of 300 to 800 nm, a thickness of about one to several μm is sufficient, and preferably 1 to 2 μm. In relation to this, the relationship between the thickness and maximum absorption wavelength of the I layer of a silicon photovoltaic element to be used for this invention is shown in Figure 9. In the Figure, the abscissa represents the wavelength of light which enters and the ordinate, on the logarithm scale, the thickness of the I layer which absorbs half the quantity of the light which enters. Accordingly it is suitable to set the positions (depths) on the substrate where the first and second photovoltaic elements are to be formed by reference, for example, to Figure 9 such that respective desired long and short wavelengths are absorbed to the maximum content.

Incidentally, when light of such a long wavelength is taken into consideration, a conventional single-crystal semiconductor requires a thickness of about ten to several tens um, but in this Invention about one to several μm is sufficient, as described above. That is, this invention enables the thickness of the semiconductor layer to be very much thinner than the prior art.

The polarities PIN or NIP of both laminated photovoltaic elements may be the same or opposite. The color of light which enters may be discriminated by utilizing the differ nc f outputs or ratios f outputs of both ph t voltaic lements, and th r by an appr priate circuit may be composed.

Hereinunder an mb diment of the inv ntion will now b explained with referenc to th accompa-

nying drawings.

Figure 1 shows the structure of an embodiment of the invention.

In Figure 1, the referential numeral 21 represents a conductive substrate or an insulated substrate having a conductive thin film thereon, 22 an amorphous silicon P (or N) layer, 23 an amorphous silicon I layer, 24 an amorphous silicon N (or P) layer, 25 a transparent conductive film, 26 a transparent insulated film, 27 a transparent conductive film, 28 an amorphous silicon P (or N) layer, 29 an amorphous silicon I layer, 30 an amorphous silicon N (or P) layer, 31 a transparent conductive film, and 32, 33, 34 and 35, respectively, electrodes. On the substrate 21, the following layers are formed in lamination in the order given: the amorphous silicon P(or N) layer 22 having a thickness of about 0.05 μm and being doped with boron (or phosphorous); the amorphous silicon I layer 23 having a thickness of about 0.5 μm and which is not doped at all or which is doped with a minute amount of boron; the amorphous silicon N (or P) layer 24 having a thickness of about 0.05μm and being doped with phosphorous (or boron); the transparent conductive film 25; the transparent insulated film 26; the transparent conductive film 27; the amorphous silicon P (or N) layer 28 having a thickness of about 0.05 μm and being doped with boron (or phosphorous); the amorphous silicon I layer 29 having a thickness of about 0.5 μ and which is not doped at all or which is doped with a minute amount of boron doped; the amorphous silicon N (or P) layer 30 having a thickness of about 0.05 μm and being doped with phosphorous (or boron); and the conductive film 31. The electrode 32 is formed on the substrate (conductive) 21, the electrode 33 on the transparent film 25, the electrode 34 on the transparent film 27, and the electrode 34 on the transparent conductive film 31.

In the above structure, a first amorphous photovoltaic element (photo diode) PD2 of a PIN structure and consisting of an amorphous solar cell is composed of the P(or N) layer 22, the I layer 23 and the N (or P) layer 24, and a second amorphous photovoltaic element (photo diode) PD1 of a PIN structure and consisting of an amorphous solar cell is composed of the P(or N) layer 28, the I layer 29 and the N (or P) layer 30. In the amorphous color sensor shown in Figure 1 the two separate amorphous photovoltaic elements PD1 and PD2 constitute one chip, the equivalent circuit of which is shown in Figure 2.

The operation of the embodiment of a color sensor according to the invention shown in Figure 1 will next be explained.

Referring to Figure 1, when light (L) enters from the side of the transparent conductive film 31, the short wavelength sensitivity becomes large in the photo diode PD1, which is closer to the light receiving surface, and in the photo diode PD2, which is closer to the substrate, the long wavelength sensitivity becomes large. These spectral sensitivity charact ristics are shown in Figure 3.

If the short-circuit curr nts generated when th photo di des PD1 and PD2 r ceiv light ar represent d by I_{sc1} and I_{sc2}, respectively, the depend ncy of th ratio of curr nts I_{sc1}/I_{sc2} upon wavel ngth is as shown in Figure 4. That is th rati of short-circuit currents I_{sc1}/I_{sc2} has one-to-one correspondence with respect to wavelength. Accordingly, it is possible to determine the wavelength of light which is received based on the characteristics shown in Figure 4, by measuring the short-circuit currents of the photo diodes PD1 and PD2 which flow when the photo diodes receive the light having a certain color, and obtaining the ratio of currents I_{sc1}/I_{sc2}.

CLAIMS

1. A color sensor comprising:
a substrate;
a first amorphous photovoltaic element having a PIN structure which is formed on the substrate;
a transparent insulated layer formed on the first amorphous photovoltaic element; and
a second amorphous photovoltaic element having a PIN structure which is formed on the transparent insulation layer.

2. A color sensor of claim 1 in which the first or second amorphous photovoltaic element is composed of an amorphous silicon P layer, an amorphous silicon I layer and an amorphous silicon N layer.

3. A color sensor of claim 1 in which the total thickness of the first amorphous photovoltaic element, the transparent insulated layer and the second amorphous photovoltaic element is one to several μm.

4. A color sensitive semiconductor structure comprising first and second photosensitive semiconducting elements arranged one overlying the other, each of said elements comprising overlying layers of opposite semiconducting material types separated by an insulating layer, the structure being so arranged that elements exhibit photosensitive responses with different frequency ranges.

5. A structure according to claim 4 wherein said elements are separated by a transparent insulating layer.

6. A color sensor substantially as herein described with reference to Figures 1 to 4 of the accompanying drawings.

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FIG. 1

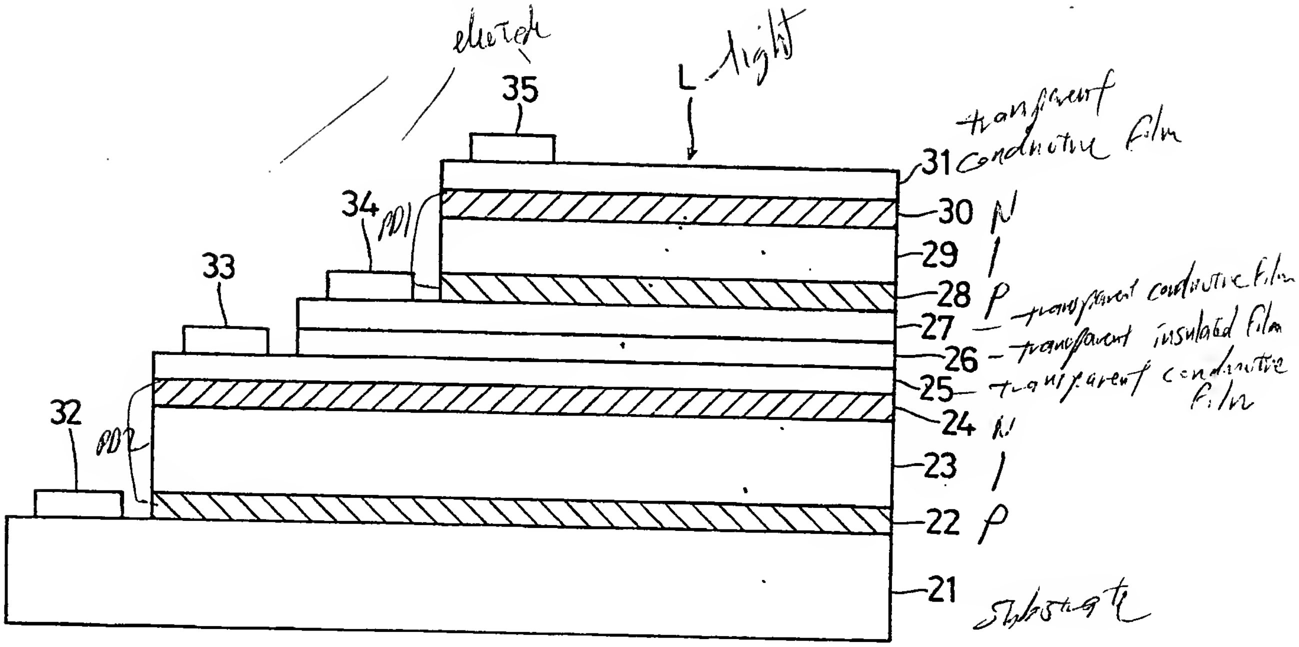


FIG. 2

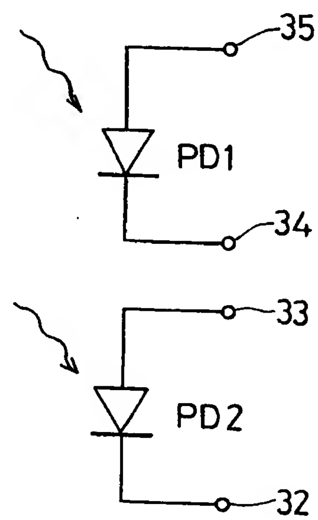


FIG. 3

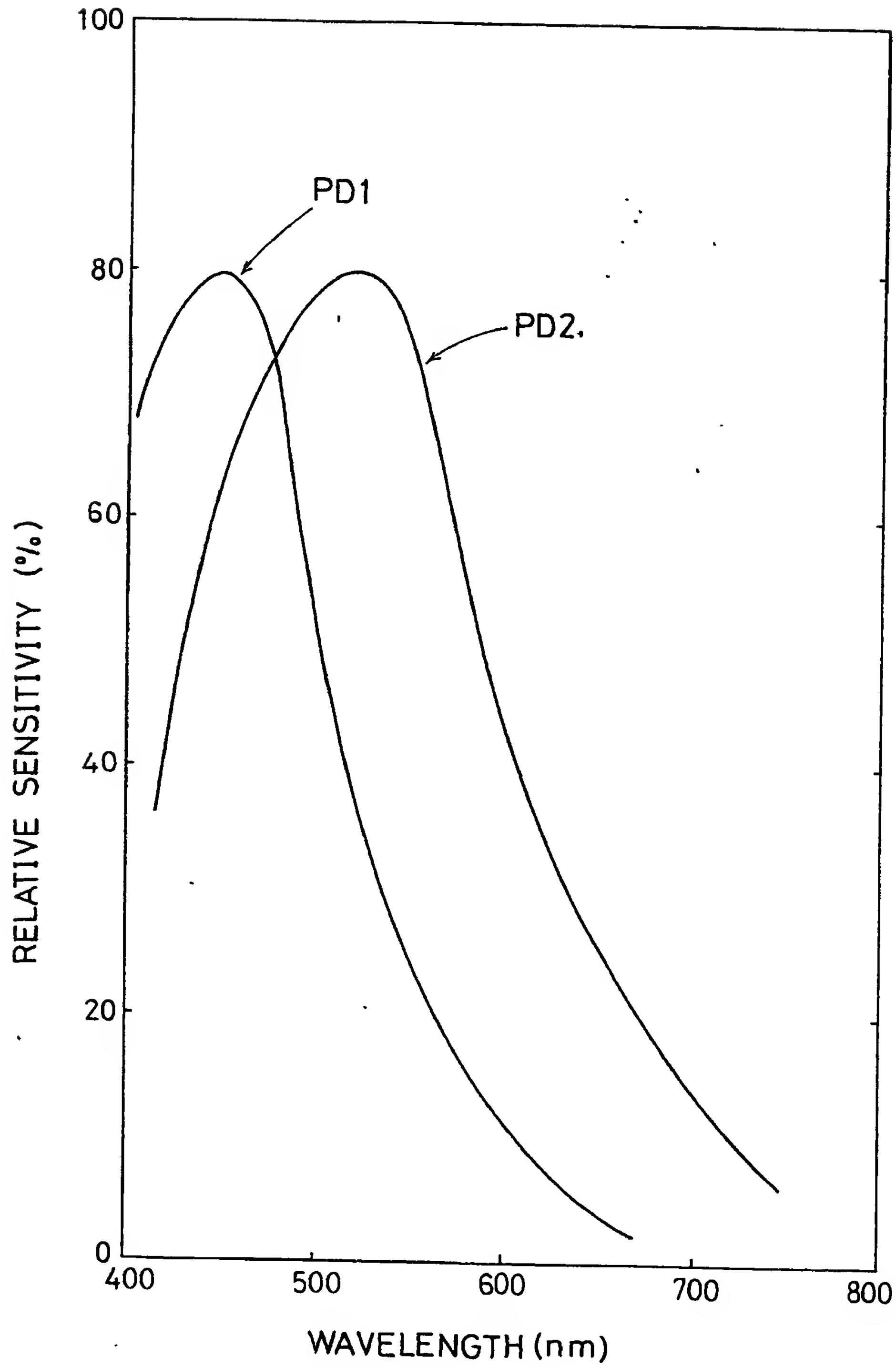

PD1
PD2.
RELATIVE SENSITIVITY (%)
100
80
60
40
20
0
400
500
600
700
800
WAVELENGTH (nm)

FIG. 4

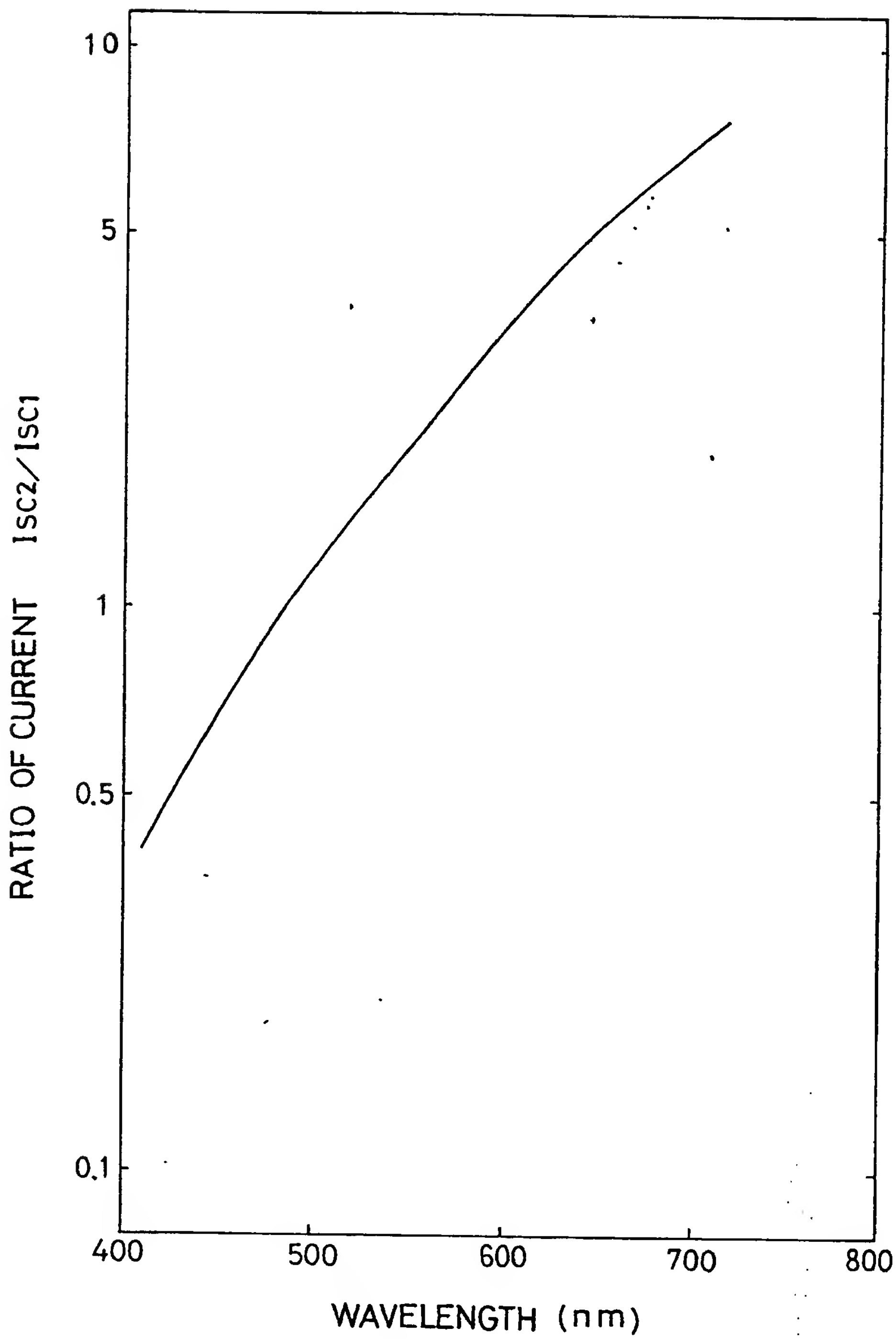

10
5
1
0.5
0.1
RATIO OF CURRENT Isc2/Isc1
400
500
600
700
800
WAVELENGTH (nm)

FIG. 5

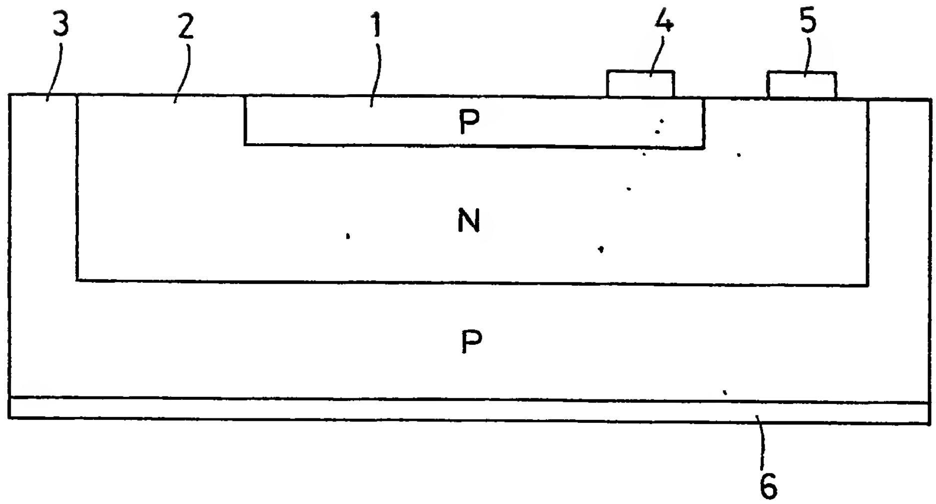


FIG. 6

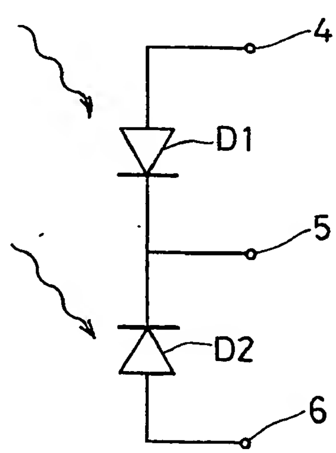


FIG. 7

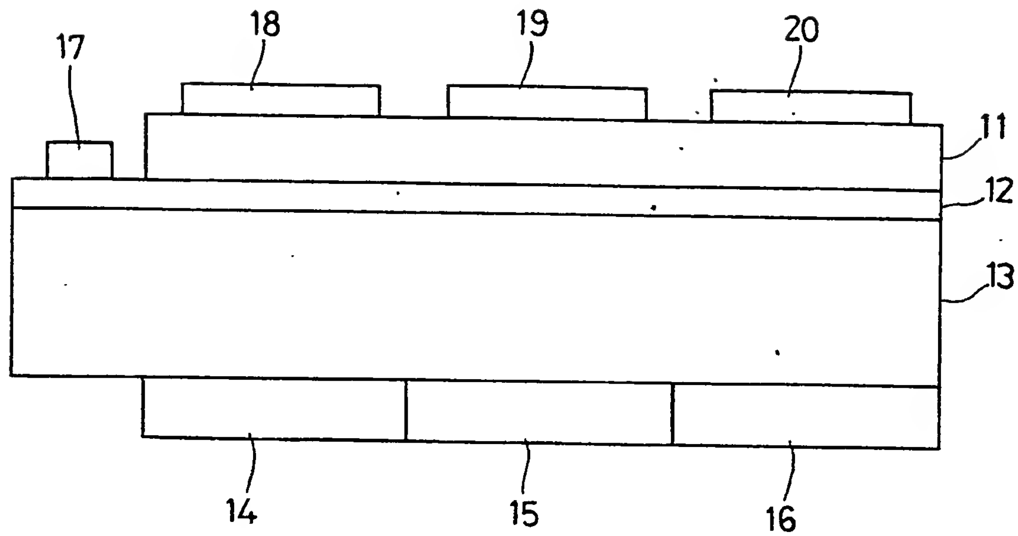


FIG. 8

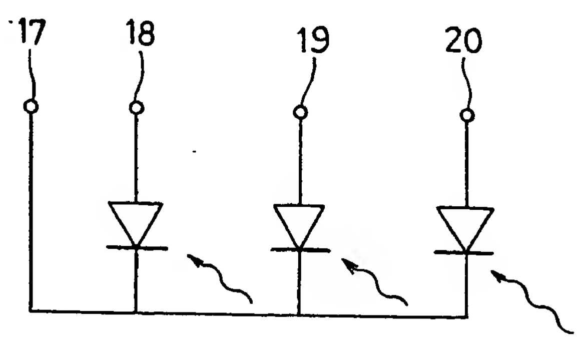
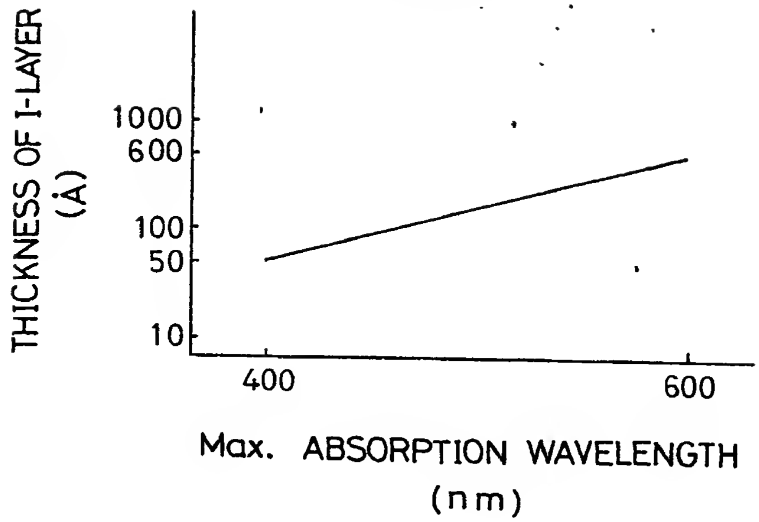


FIG. 9


THICKNESS OF I-LAYER
(Å)
1000
600
100
50
10
400
600
Max. ABSORPTION WAVELENGTH
(nm)